A Kirkpatrick-Baez Option for the optics of an X-ray observatory with a 50 m focal length

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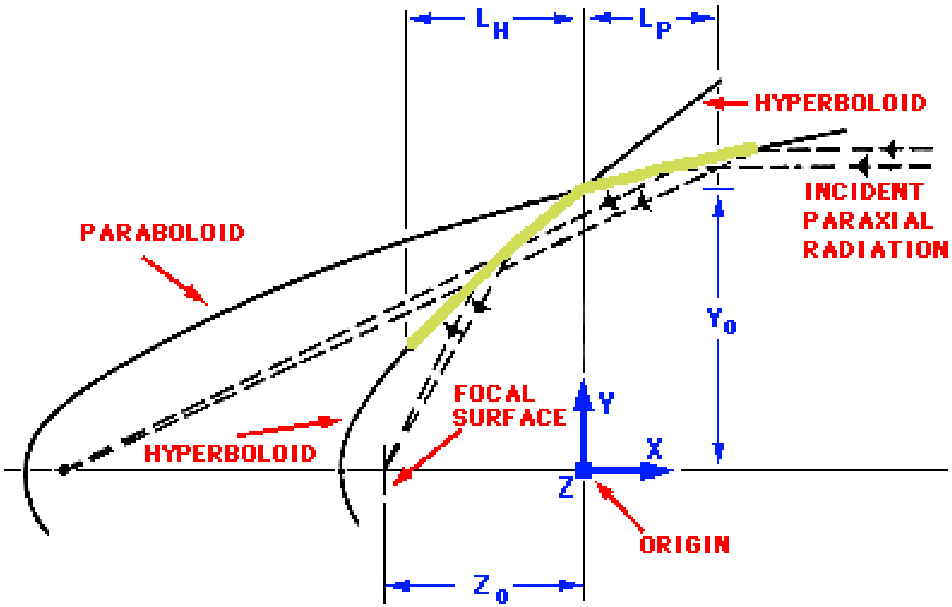
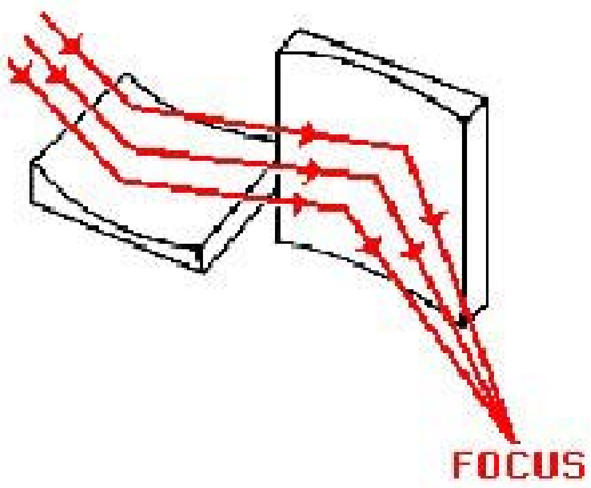
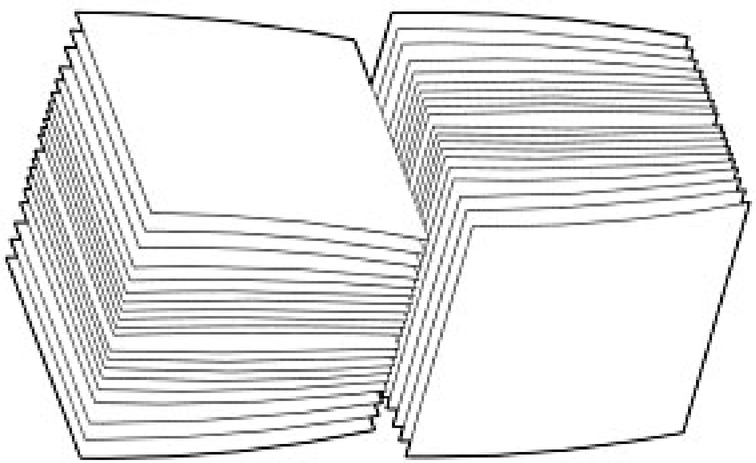
Wolter Type 1 Optics



The Wolter geometry is superior for most applications (and always has higher throughput) but perhaps not for the Si pore architecture with respect to angular resolution.

The Kirkpatric-Baez Geometry, Orthogonal Parabolas



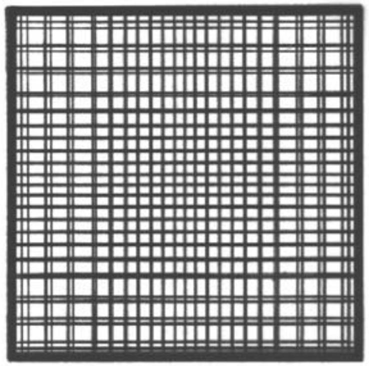


Proposition: **The K-B geometry should be considered for a large diameter, long focal length telescope, both the "conventional" thermally formed glass and Si pore optic. In particular it may better adapted to and present less difficulty than the Wolter in the construction of a large modular Si pore telescope with good angular resolution.**

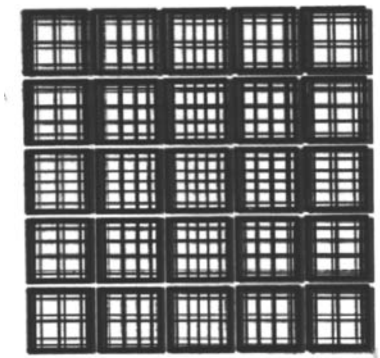
Physical Resemblance of Modular KB Array with Si Pore Array.

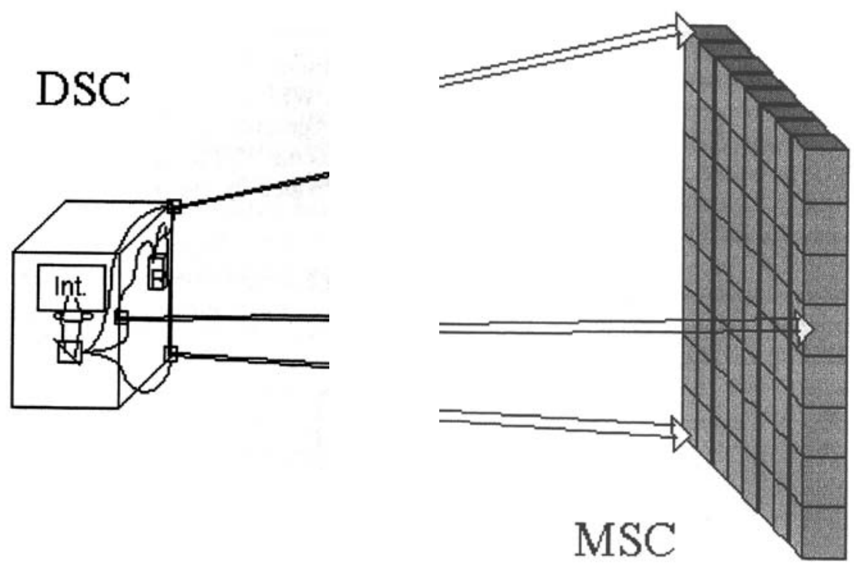
Both seem to be more compatible with a rectangular geometry.

KB Telescope Front



KB Modular Array



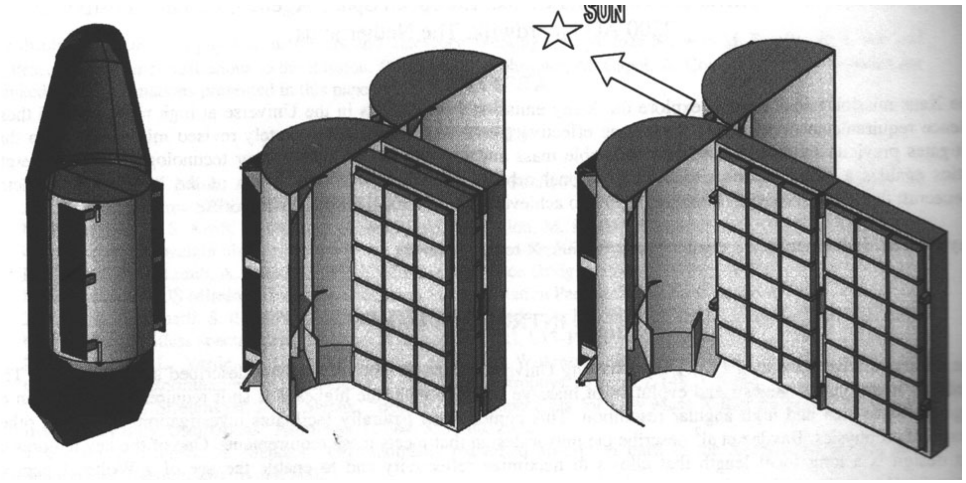


Si Pore Telescope Formation Flying with Detector S/C

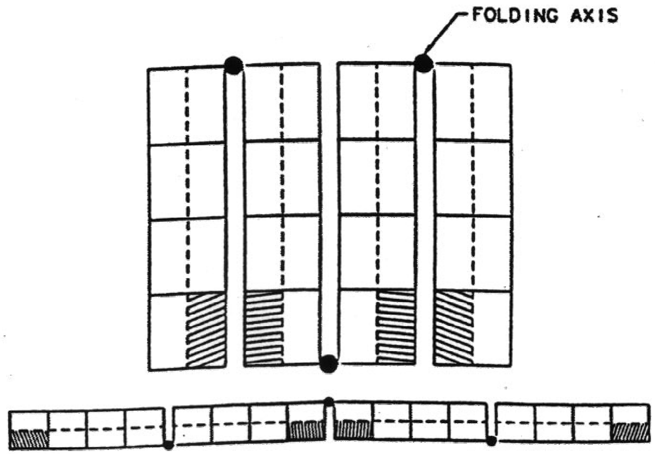
Bavdaz et al, 2004

The rationale

The resemblance may be more than superficial. The Si pore telescope is essentially a modular array of quasi flat reflectors, which also describes a modular KB telescope



Bavdaz et al, 2004/SCI-A/010



Gorenstein, 1998 SPIE 3444, 382

Overcoming inherent resolution problems of an unmodified orthogonal parabola geometry

Two angular resolution problems are associated with orthogonal parabolas

- Reflection from the 2nd stack of reflectors affects the path of rays reflected by the 1st stack causing rays far from the center to intersect the optic axis prematurely

- In a conventional geometry the off-axis angular resolution not as good as the Wolter's.

Off-Axis Resolution

L : Length of reflector, θ is the angle off-axis, α is the graze angle

F : Focal Length

$$\sigma(\theta) := \frac{1}{5} \cdot \frac{\tan(\theta)^2}{\tan(\alpha)} \cdot \frac{L}{F}$$

Wolter

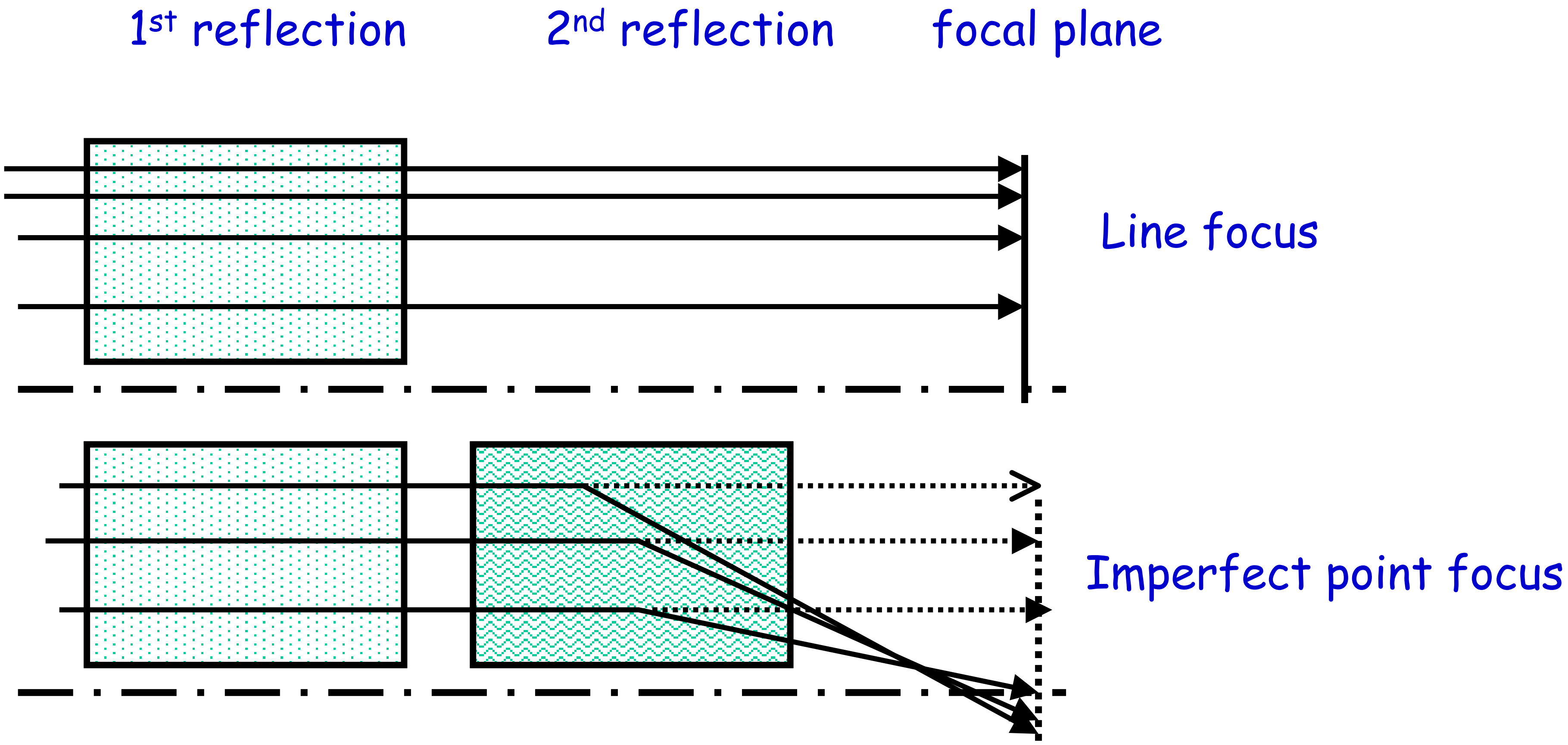
$$\sigma(\theta) := \frac{L}{F} \cdot \theta$$

K-B

For Si pore optic, L = 75 mm, F = 50 m
At 5 arcmin off axis, the K- B resolution is 0.45 arcsec,

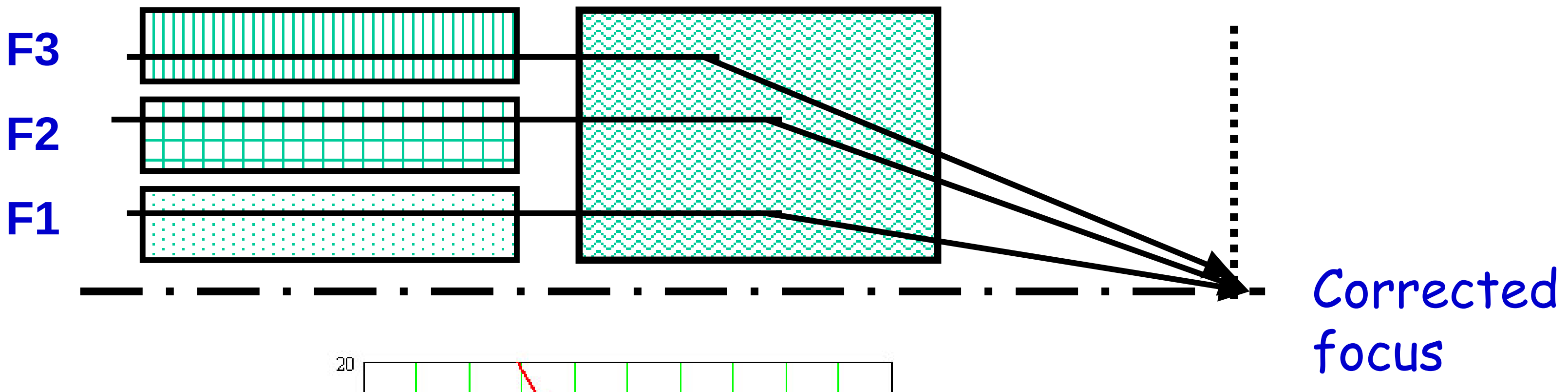
For thermally formed “conventional” optic, L = 40 cm, F = 50 m
At 5 arcmin off axis, the K- B resolution is 2.5 arcsec, acceptable (?)

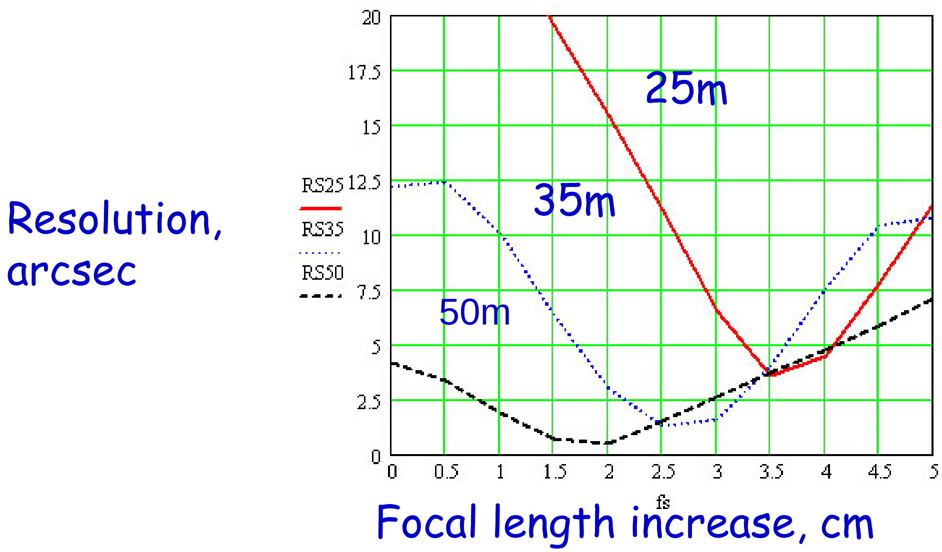
Aberration caused by 2nd reflection



Correcting Aberration by Varying Focal length of front stack with vertical distance from optic axis.

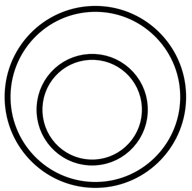
F3 > F2 > F1



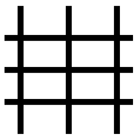


Ray tracing study of improving focus by varying focal length of outer modules

Advantages of the Wolter optic, all conditions



- Higher throughput, more efficient stacking, lose area due to finite thickness of reflector only once. K-B loses in 2 dimensions



- Broader bandwidth, thanks to smaller graze angles
- In formation flying, it is insensitive to changes in telescope pointing, i.e. acts like a thin lens. (Not an advantage with an optical bench.
- Superior angular resolution in theory (perhaps not in practice for this application)

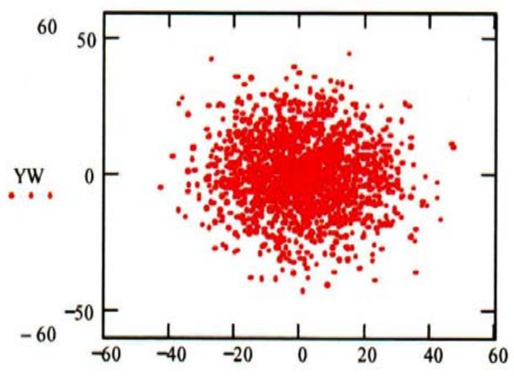
- However, in this size the substrates are no longer integral cylinders and no longer have an advantage in rigidity compared to flats.

Advantages of the K-B Optic

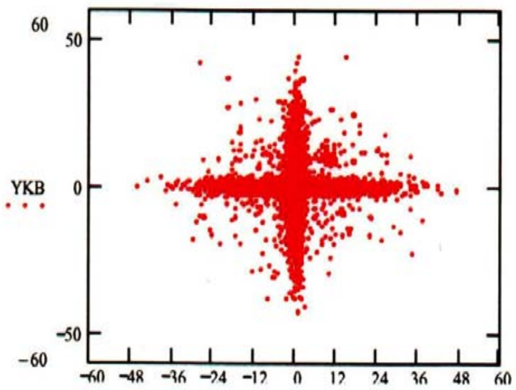
- All reflectors are flats or near flats, especially for Si pore, no curvature along azimuth
- Linear geometry results in easier alignment of each set of modules
- No mandrels are needed
- Can construct front and rear sections separately
- Line images facilitate co-alignment of modules, ie. reduce problem of identifying misaligned module from checking N^2 to N modules in each stack
- Alignment of front and rear sections is non-critical
- Therefore, can insert baffles between front and rear sections to exclude stray light.
- Scattering is confined to axes, improving images

Faint source near strong source

Wolter Optic



K-B Optic



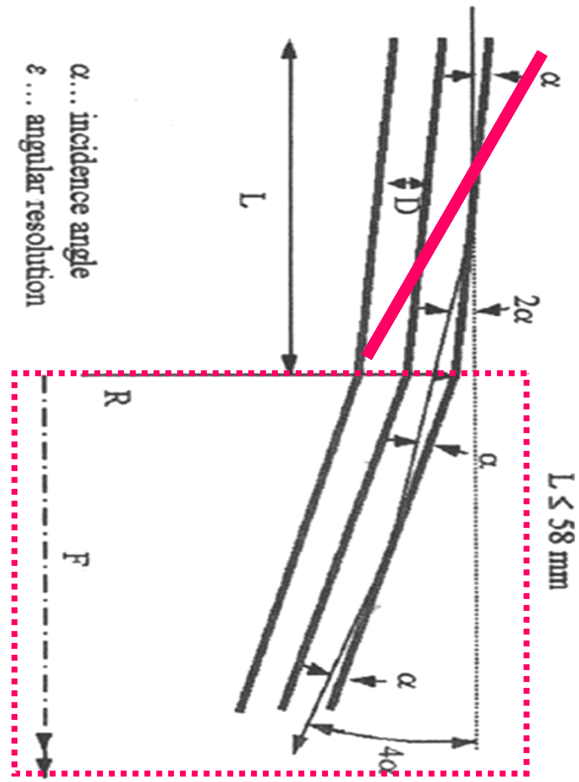
Ray tracing simulation using XMM-Newton point response but also applicable to higher resolution optics on smaller scale.

Reflectors

Conical

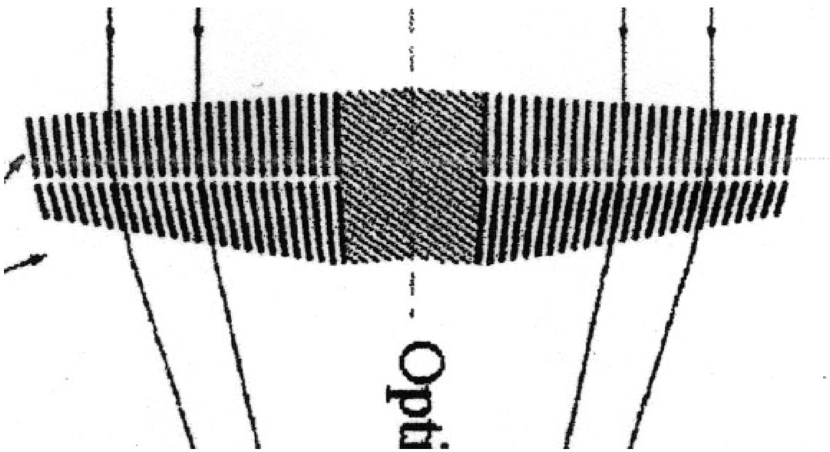
K-B front

K-B rear



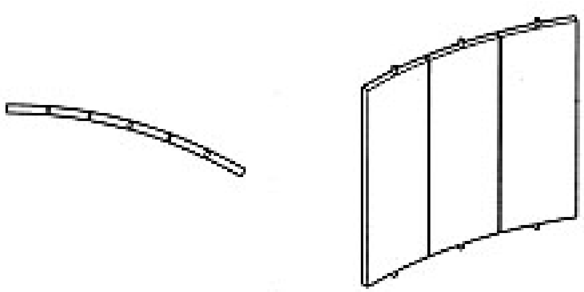
Graze angles of K-B reflector is twice the conical

Segmenting reflectors to improve linear approximation



Double conical Si pore optic

Figure can also represent two stage K-B optic that would improve linear approximating of longer, more efficient, reflector by changing orientation of successive portions



Summary

- A single focus, large telescope can be constructed more easily and with better angular resolution with a K-B geometry than the Wolter or double conicalgeometry. Better resolution compensates for less throughput with respect to faint source sensitivity.
- The rectangular and flat plate geometry of the K-B seems to be a good match to the Si pore telescope in particular.
- The stiffness advantage of integral cylindrical shells, e.g. ROSAT, Chandra, XMM, no longer applies for a large segmented telescope, depriving the Wolter of a resolution advantage over the K-B
- The front dimension aberration of a K-B telescope is correctable by varying the focal length slightly with distance from the optic axis.
- The off-axis resolution of the K-B is acceptable for the proposed dimensions with a smaller L/F than the previous Con-X SXT. Applies to both Si pore and thermally formed glass telescopes.